ADDRESS

Delivered by the President, Mr. W. H. Maw, on presenting the Gold Medal of the Society to Professor W. W. Campbell.

THE Gold Medal of the Royal Astronomical Society has this year been awarded to Professor WILLIAM WALLACE CAMPBELL "for his spectroscopic researches, which have greatly increased our knowledge of stellar motions"; and it is my pleasant duty to-day to lay before you some particulars of the work which our Medallist has carried on with such persistent energy, and with most marked success, for so many years past.

The determination of stellar velocities in the direction of the line of sight is a branch of astronomical research which has engaged the attention of such a comparatively small band of workers that I may perhaps be allowed—even when speaking to an audience like the present—to devote a few moments to a brief sketch of its history and development. As is well known, the determination of radial velocities depends upon the fact, pointed out by Doppler as long ago as 1842, that the wave-length of light reaching the eye is affected by the motion of the source of light in the radial direction. A few years later, in 1848, Fizeau showed that the lines of the spectrum could be turned to account to determine the changes of refrangibility due to motion of the light source; but it was not until 1866 that steps were taken to utilise this fact for the measurement of stellar velocities in the line of sight. In that year the matter was taken in hand by Sir William Huggins; and having in the following year succeeded in devising and constructing suitable instrumental arrangements, he was able in 1868 to contribute to the Royal Society a paper giving the results of observations on the displacement of the F line in the spectrum of *Sirius*, thus laying the foundations of a new branch of astronomical research, which has since yielded such valuable and far-reaching results.

In 1871 observations of radial velocity were taken up by Vogel at Bothkamp, while Huggins continued to improve his equipment and increase the number of stars observed by him. The work was also taken up at Greenwich, where many observations were made by Maunder, and at Rugby, by Seabroke. In all these cases the observations were made visually, and the

difficulties attendant upon the measurement of the shift of the lines were so great that the results obtained varied very widely, and it was felt generally that the velocities deduced were not such as to inspire entire confidence in their accuracy.

This state of affairs continued until, in 1888, a very decided step in advance was made at Potsdam by H. C. Vogel, who, in place of continuing the visual observations, arranged to measure the displacement of lines in stellar spectra which had been recorded by photography. This change in the mode of working possesses many important advantages. By the use of prolonged exposures it renders available for measurement faint spectra with which it would be practically impossible to deal visually; while the measures can be made at leisure, under convenient conditions, and can be repeated as desired. On the other hand, the photographic method of working has difficulties of its own of no mean order, and the attainment of successful results by it involves in a very high degree the possession of skill, experience, and patience on the part of the worker.

One of the earliest results of the employment of the photographic method of observing stellar spectra was the discovery of the class of stars now generally known as spectroscopic binaries. For convenience it is common to speak of these binaries as divided broadly into two classes: namely, first, those in which each of the components is sufficiently bright to yield a spectrum which can be observed and measured; and, second, those in which one of the components is either dark, or so faint that the spectrum of one only of the components can be recorded with the instruments available. Strictly, of course, these two classes are not distinct, there being all gradations of intermediate pairs, representing different proportions of brilliancy of the two components; but the classification has, nevertheless, its convenience, as it indicates the difference in the methods by which the pairs can be observed. In stars of the first class the difference between the movements in the line of sight of the two components is indicated by the shift of the lines of one spectrum relatively to those of the other; and the measurement of this shift (and consequently of the radial movement corresponding to it) is thus quite independent of the radial motion which the system as a whole may have relatively to the Earth. Pairs of this class can thus be observed by the aid of slitless spectroscopes, such as the object-glass prism, the orbital motion of the two components being indicated by the periodical doubling and undoubling of certain lines in their spectra.

In the case of the second class of spectroscopic binaries, on the other hand, the determination of the orbital motion depends upon the measurement of the variable radial motion of the bright component in the line of sight relatively to the Earth; and this necessitates a comparison of the stellar spectrum with the spectrum of an artificial source, in order that the shift of certain lines, due to the radial motion of the star, may be

measured. It is evident, of course, that unless the motion of the star at any given moment relatively to the Earth can be ascertained with a high degree of accuracy, it will be quite useless to attempt to deduce the orbital motion of a spectroscopic binary from any variation in such measured movement. The development of this branch of spectroscopic astronomy has thus only been secured by the gradual introduction of various instrumental refinements, combined with the recognition of the sources of error, and the exercise on the part of the observers of care and skill of the very highest order. Amongst those who have contributed to this progress none are entitled to a higher place than he to whom your medal has this year been awarded. Of course the discovery of spectroscopic binaries is in no sense the primary object of the measurement of radial velocities; but the fact that binary pairs of this second class can now be effectively dealt with is in itself a proof of the advances which have been made.

The first spectroscopic binary to be discovered was ζ *Ursæ Majoris*. In the third Annual Report of the Henry Draper Memorial, issued in 1889, Professor Pickering called attention to the fact that in the spectra of the star photographed at Harvard the K line occasionally appeared double. Photographs of the spectrum taken at intervals extending from 1887 March to 1889 October were carefully examined by Miss A. C. Maury; and eventually evidence was obtained pointing clearly to the conclusion that this doubling of the K line was due to the orbital motion of a pair of bodies giving spectra of the same type and of approximately equal brightness. ζ *Ursæ Majoris* thus belongs to the first-named class of spectroscopic binaries, and its discovery was closely followed by a second—namely, that of β *Aurigæ*, Miss Maury announcing, late in 1889, that lines in the spectrum of this star became alternately double and single every forty-eight hours, thus giving the pair a period of four days.

The first spectroscopic binary of the second class to be discovered was *Spica* (α *Virginis*), the duplicity of which was announced in 1890 by Dr. Vogel, who had during the previous year determined spectroscopically variations in the radial velocity of *Algol* (β *Persei*), and had thus endorsed the deduction of its binary character founded on observations of its varying luminosity. From that time the discovery and examination of close binary systems by spectroscopic means have gone steadily on, and admirable work has been done, notably in Europe, by Vogel and Scheiner at Potsdam, Belopolsky at St. Petersburg, Newall at Cambridge, and Deslandres at Meudon; and on the other side of the Atlantic by Professor Pickering and his colleagues at Harvard, by Frost and Adams at the Yerkes Observatory, by Slipher at the Lowell Observatory, and lastly—but in this case certainly very far from least—by Professor Campbell and his colleagues at Mount Hamilton. At the present date the number

of known spectroscopic binaries amounts to some 146, and of these nearly one-fourth have, as we shall see later, been discovered by our Medallist personally.

The measurement of stellar velocities in the line of sight by visual methods was taken up at the Lick Observatory some fifteen years ago, when measures were made by the late Professor Keeler, and subsequently by Professor Campbell and Dr. Crew. It was at this period that the late Professor Keeler made, with a grating spectroscope, his magnificent series of measures of the radial velocities of fourteen nebulæ. This work was of the highest order, but the feebleness of light for visual measures led to work in this branch of research being discontinued; and the determination of radial velocities cannot be said to have formed an item in the regular programme of work at Mount Hamilton until the construction of the Mills Spectrograph in 1895. The installation of this spectrograph, as well as its partial reconstruction some six years later in accordance with the experience then acquired, was rendered possible by the generosity of Mr. D. O. Mills; and in designing it Professor Campbell determined to sacrifice any considerations which would interfere with its convenience and efficiency for the determination of stellar velocities in the line of sight, using the Hγ region of the spectrum. It would be impossible—even if it were desirable—in the time available to-day, to give anything like a detailed description of the Mills Spectrograph, and I must, therefore, confine myself to a few brief notes concerning it.

The Lick telescope has a clear aperture of 36 inches and a focal length of 58 feet, the focal length for the Hγ rays, however, being 1·9 inches longer than for the D rays, a fact which affected a certain feature in the design of the spectrograph, as will be seen later. The collimator of the spectroscope has a double lens of Jena glass, 1·78 inches clear aperture stopped down to 1·5 inches, and a focal length of 28·4 inches. It gives a circular beam of Hγ light, 1·5 inches in diameter, received by a train of three dense flint prisms of such density and angle as to give a total deviation of about 180 degrees.

As regards resolving power, the instrument has been found fully capable of realising the theoretical limits appropriate to its proportions. In the case of the solar spectrum the observed purity has for practicable slit widths been found somewhat greater than its computed value; while in the case of some stellar spectra photographed on rapid plates, with a slit-width of 0·02 millimetre, lines $\lambda\lambda$ 4337·216 and 4337·414 are shown separated; the difference in wave length—namely, 0·198 tenth-metre—being in these instances exactly the theoretical limit for the width of slit used.

The steepness of the colour curve of the object-glass of the Lick telescope, to which I have already referred, led to a difficulty in the guiding of the instrument when the spectrograph was in use. With the slit placed on the Hγ focus, the Hγ image

of a star is a point in the centre of a comparatively large disc of light due to rays of various refrangibilities, and the central point cannot be seen with sufficient distinctness to be used for guiding. This rendered inapplicable Sir William Huggins's simple plan of using reflecting slit plates. Other known methods had disadvantages of their own, and at length, after many experiments, Professor Campbell decided to use light reflected from the first prism surface to form a guiding spectrum, this reflected light passing through a thirty-degree prism to the guiding telescope. An occulting bar in the eyepiece covers all the spectrum except the $H\gamma$ region, this region being linear as the $H\gamma$ rays are in focus on the slit. If the $H\gamma$ image fails to be on the slit, a gap occurs in the guiding spectrum. This guiding device has proved quite satisfactory.

It is the practice at the Lick Observatory to use the big telescope for spectroscopic work on three nights in each week, the remaining nights being devoted to double-star work, &c. Provision had, therefore, to be made for readily and safely attaching and detaching the spectrograph, and the arrangements for this purpose have been so well worked out that the change from micrometer to spectrograph, or *vice versa*, can be easily effected by one person in six minutes.

I have said that the determination of the radial velocities of stars by the measurement of photographed spectra is a system of working attended with special difficulties of its own, and perhaps a few figures relating to the practice at Mount Hamilton may serve to show the delicacy and accuracy necessary. With the Mills Spectrograph an exposure of about fifteen seconds, with a slit width of 0·015 millimetre, will record the spectrum of *Sirius*, but for a fifth-magnitude star about an hour's exposure with a slit width of 0·025 millimetre is necessary under average conditions. The width of the spectrum obtained is about 0·3 millimetre. The comparison spectra used are those of hydrogen and iron, an exposure of five seconds sufficing for the $H\gamma$ line, while in the case of the iron spectrum about three seconds is given for the brighter, and about sixty seconds for the faint lines, a device being provided for occulting the brighter lines after a short exposure has been made.

The measurement of the spectra is effected by a micrometer microscope, which is a duplicate of that employed at Potsdam. It has a screw of 0·25 millimetre pitch, the head being divided into 100 parts, and being capable of being read to tenths of a division. Three settings are made on each of the star lines selected for measurement, and a corresponding number on the lines of the comparison spectrum, corrections being, of course, introduced for the curvature of the spectrum lines. Speaking of these measures, Professor Campbell has said: "The extreme accuracy required and attained in this class of work is evident from the following statement: The linear value of 0·01 second of arc in the focus of the 36-inch refractor is 0·000857 millimetre.

On the spectrum plates 0·000857 millimetre is 0·0034 revolution of the screw, corresponding to 0·74 kilometre per second displacement.* It is not surprising, therefore, that great care and considerable experience are absolutely necessary for suitable measurement of the plates. The lines to be measured require good judgment in their selection. Some of the best lines in the solar spectrum are practically useless in many stars, owing to the changed intensities of close companion lines."

From the measured displacement of the stellar lines the corresponding radial velocity can be calculated, but the velocity so obtained is that of the star relative to the observer at the time of the observation; and before the motion of the star relative to the sidereal system can be ascertained four components must be eliminated. These components are due (1) to the rotation of the Earth on its axis; (2) to the revolution of the Earth round the common centre of gravity of the Earth and Moon; (3) to the revolution of the Earth round the Sun; and (4) to the motion of the solar system as a whole. For determining this last correction we are not yet in possession of sufficient data, and the practice at present, therefore, is to reduce stellar radial velocities to the Sun by the application to the observed velocities of the three first-named corrections. The application of these corrections and other calculations relating to the spectroscopic determination of velocities have been much facilitated by a valuable series of tables prepared by our Medallist.† In an introduction to these tables, Professor Campbell says: "The remarkable accuracy of recent spectroscopic observations requires that the corrections be applied to the nearest tenth of a mile (= 0·16 kilometre) per second. The still greater accuracy which may be reasonably expected in the future will require that they be applied to one-hundredth of a mile (= 0·016 kilometre) per second, and such is the limit of precision adopted in these tables." The success which has attended our Medallist's own work in this direction seems to amply warrant the forecast made in the words I have just quoted.

The Mills Spectrograph was first used in 1895 May, but it was nearly a year later before all adjustments had been completed and sources of error eliminated. Between the summer of 1896 and the end of 1900 some 2000 spectrograms were obtained, these including some 1500 spectrograms of 325 stars situated between the North Pole and declination −30 deg. Of these last-named spectrograms between 300 and 400 related to spectroscopic binaries, nearly fifty plates being required for the investigation

* In other words, the displacement of a line corresponding to a velocity in the line of sight of 1 kilometre per second is equal to about $\frac{1}{865}$th of a millimetre, or, say, $\frac{1}{21800}$th of an inch.

† *Astronomy and Astrophysics*, vol. xi. p. 319. The Tables, modified to suit the adoption of the kilometre as the unit of velocity per second, are also given in Frost's translation of Scheiner's *Treatise on Astronomical Spectroscopy*, p. 338.

of ζ *Geminorum* alone. Since that time the work has gone on steadily and with ever-increasing accuracy, and in April last year Campbell was able to bring out the first published catalogue of spectroscopic binaries: a catalogue which is in itself ample evidence of the importance of the work done by our Medallist.

From this catalogue it will be seen that at the end of 1904 140 spectroscopic binaries were known, and of these no less than fifty-eight had been discovered by the aid of the Mills Spectrograph at the Lick Observatory, and fourteen by the D. O. Mills Expedition to the Southern Hemisphere, making seventy-two, or more than half the total, discoveries stand to the credit of the Lick Observatory staff. The more recently constructed Bruce Spectrograph of the Yerkes Observatory makes an excellent second, with forty-one discoveries to its credit. Of the fifty-eight spectroscopic binaries discovered at Mount Hamilton up to the end of 1904 no less than half—twenty-nine—were discovered by Campbell himself, and five more by Campbell working in conjunction with another observer. During 1905 the number of binaries recorded in the catalogue just referred to has been increased by six, of which three have been discovered at the Yerkes Observatory, two at Mount Hamilton, and one at the Mills Observatory, Santiago. Up to the present the radial velocities of some 500 stars have been determined at Mount Hamilton, and of about 200 more by the D. O. Mills Expedition to Chile, and the whole of this extensive and most important work has been inaugurated by our Medallist, and carried out—much of it by himself personally—in accordance with the programme which he had drawn up.

Nor is the importance of our Medallist's work on the determination of radial velocities and the characteristics of spectroscopic binaries to be judged simply, or even chiefly, by its amount. Of even greater value is the influence which he has personally exerted on the accuracy of observations of radial velocity. Writing on this point in 1904, in the publications of the Yerkes Observatory, Professors Frost and Adams said: "The next great advance was made by Campbell, in his design of, and work with, the Mills Spectrograph of the Lick Observatory. . . . The use of iron as a comparison spectrum (previously tried by Vogel and Deslandres, but not regularly employed by them), together with the closest attention to the optical and mechanical construction of the instrument, and great refinement in the measurement of the plates, enabled Campbell to increase greatly the accuracy of the determinations; so that the natural unit became the kilometre per second, instead of the sevenfold greater German geographical mile employed by Vogel."

Our Medallist's views as to the future development of this branch of spectroscopic work are naturally of great interest. Up to the end of 1904, he tells us, at least one in seven of the stars examined by the Mills Spectrograph appears to be an

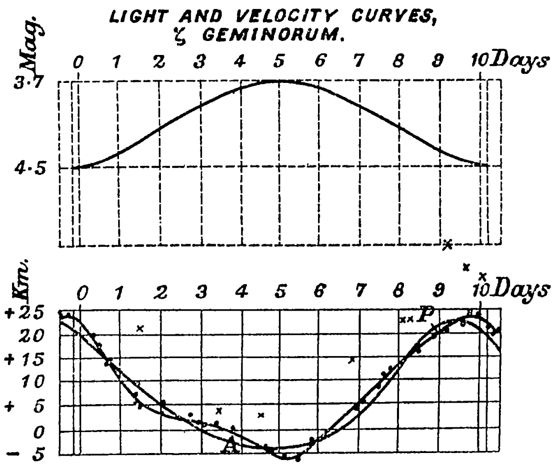
invisible binary of short period. In the case of the Bruce Spectrograph at the Yerkes Observatory, where stars of the "Orion" type have been especially studied, the proportion of binaries has been much greater—namely, about one in three.

It must be remembered, however, that the spectroscopic binaries, so far discovered, are naturally those having relatively short periods, and showing therefore considerable variations in velocity, the smallest variation so far recorded as showing a binary character being in the case of *Polaris*, namely, 6 kilometres per second. But much smaller variations than this may really be indicative of orbital motion; and there is every probability that, as time goes on and data accumulate, spectroscopic binaries may be numbered by thousands. One limit to our present investigations lies in the enormous loss of light in passing through a train of prisms, and in the fact that in the spectrum the light of a star is spread over a comparatively large area. Professor Campbell regards the 8th magnitude as probably the smallest which can be successfully observed by existing appliances, and he considers that obtaining the spectrogram of a 9th magnitude star using only moderate dispersion is comparable with photographing a 20th magnitude star by the aid of our most powerful reflecting telescopes.

If time permitted much could be said respecting the special features of many of the spectroscopic binaries which have been discovered by our Medallist, but I must content myself with some brief notes on three only. The first of these is ζ *Geminorum*, a well-known variable, which I have already had occasion to mention. Its binary character was discovered by Belopolsky in 1898 January, but no announcement of the discovery appears to have been published, and the duplicity of the star was independently discovered by Professor Campbell in 1899 January, and announced by him the following month. Between 1898 November and 1900 February forty-four spectrograms of ζ *Geminorum* were secured at Mount Hamilton, and these were duly measured and reduced, with the result that they showed clearly that the pair had an orbital movement corresponding to the period of its light curve—namely, 10·154 days, the observed velocity in the line of sight varying from +24·2 to −6·7 kilometres per second.

The diagram on page 253 shows in the upper figure the light curve of ζ *Geminorum*, and in the lower figure the radial velocities, the thick line showing the velocities as observed, and the thin line the velocities corresponding to an elliptic orbit, which Professor Campbell selected as affording probably the best possible elliptic representation of the observed curve. The observations extend over forty-five complete periods, and it will be noted that the two curves intersect six times during a period. Professor Campbell has remarked that the disturbances in the observed curve might be explained by assuming that ζ *Geminorum* was a triple system, but he considers that they are more

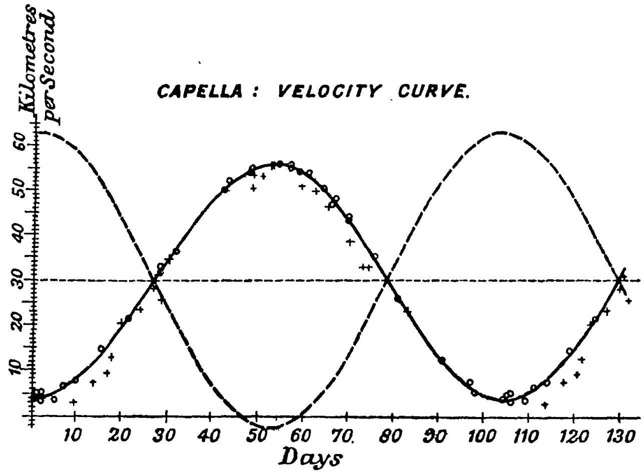
probably due to tidal effects caused by the comparative proximity of the two components revolving in an eccentric orbit.



The next spectroscopic binary which I shall mention, namely, *Capella*, has a special interest for British astronomers, inasmuch as its binary character was discovered independently by our Medallist at Mount Hamilton and by Mr. Newall at Cambridge within a very brief period, Professor Campbell making his announcement at the meeting of the Astronomical and Astrophysical Society of America in 1899 September, while Mr. Newall submitted a note on his discovery at the meeting of our Society in November of the same year. During 1900 also the pair was observed with the 28-inch equatorial at Greenwich, and a number of micrometer measures were made, with results pointing to an orbit closely agreeing with that deduced from spectrographic observations.

According to Professor Campbell the spectra of the two components are distinguishable on most of the spectrographs taken, that of the principal star being of the solar type, and that of the other something between the solar and Sirian types, and the presence of the latter spectrum adds materially to the difficulties of measuring that of the chief component. From data based on thirty-one spectrographs taken between 1896 September and 1900 September Campbell deduced for the chief component a range of velocity in the line of sight from $+4{\cdot}2$ to $+55{\cdot}7$ kilometres per second, and for the second component a range from -3 to $+63$ kilometres per second; while for the velocity of the centre of mass of the system he arrived at the value $+30$ kilometres per second. On computing the orbit, the period determined as best agreeing with the observations was one of $104{\cdot}1$ days, the orbit having an eccentricity of $0{\cdot}02$. The diagram on page 254 records these figures, and shows the computed velocity curve, abscissæ representing times and ordinates velocities in the line of sight, while the dotted horizontal line indicates the velocity of the centre of mass. The dotted curved

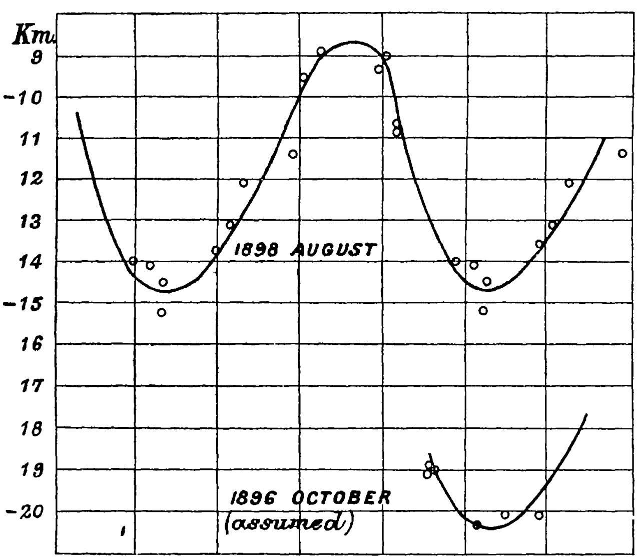
line indicates, approximately, the variable radial velocity of the lesser component.



On the diagram the Mount Hamilton observations are represented by circles, while Mr. Newall's observations are plotted as crosses; and it will be seen that a small reduction in the velocity of the centre of mass would bring the two sets of observations into fair agreement. I should add that Mr. Newall's computation of the probable orbit, as given in his paper published in *Monthly Notices* for 1899 November, also gives a period of 104 days.

The last spectroscopic binary to which time will permit me to refer in any detail is *Polaris*, a star the motion of which is marked by some very special features. Between 1896 Septem-

VELOCITY CURVE OF POLARIS.



ber 8 and December 8 six spectrograms of *Polaris* were obtained by Campbell, and these gave very consistent results, the mean

radial velocity deduced being one of −19·6 kilometres per second. In 1899 August, however, another spectrograph gave a velocity of −13·1 kilometres per second, and this led to a further series of observations being made, with the result that between 1899 August 9 and 30 velocities varying from −8·6 to −15·2 kilometres per second were obtained. On plotting these results it was clearly indicated—as shown by the diagram on page 254—that *Polaris* was a binary with a period of rather less than four days. The diagram also shows the 1896 results, and the discrepancy between these and the observations of 1899 remained to be explained. Since 1899 *Polaris* has been regularly observed spectroscopically at Mount Hamilton, and the results of these observations are given in the table subjoined, which also includes the results of 1896 and 1899.

Observations of Polaris at the Lick Observatory.

Date.	Velocities in the Line of Sight at Positions of Minima. Kilometres per Second.
1896·9	−20·67
1899·8	−14·22
1900·6	−14·64
1901·4	−16·32
1902·6	−16·79
1903·0	−17·18
1903·7	−17·84
1904·5	−18·52

Professor Campbell's deduction from his observations is that *Polaris* is a triple system, the rapid pair having a period of 3 days 23 hours 14 minutes, and that the velocity of the centre of mass of this pair is changing along a velocity curve corresponding to a period of at least eleven years, but which may be considerably longer. It is evident that some years must still elapse before any really definite determination of this longer period can be arrived at, but meanwhile the progress of the observations at Mount Hamilton will be followed with the greatest interest.

By the year 1901 our Medallist had accumulated enough data relating to radial velocities to justify him in utilising his results for a first rough determination of the Sun's way. For this purpose he used the motions of 280 stars, and these he divided into eighty groups, the mean of the velocities of the stars forming a group being taken as the velocity of that group. Equations of condition were obtained for the eighty groups, each equation being weighted in proportion to the number of stars contained in the group to which it referred, and the eighty equations were then combined and solved by the method of least

squares. The position thus obtained for the apex of the Sun's way was R.A. 277° 30′ and declination +19° 58′, while the Sun's velocity was 19·89 kilometres per second. The right ascension thus found agrees exactly with Newcomb's, and differs only $1\frac{1}{2}$° from Kapteyn's, but in the value of the declination there is a material divergence, Newcomb's declination being 15° and Kapteyn's 14° greater. This result is attributed by Campbell to the extremely unsymmetrical disposition of the groups of stars used in his determination, there being a great dearth of Southern stars—a deficiency which gave rise to the Mills Expedition to Santiago. The organisation of this expedition may well be cited as a splendid example of the thoroughness and vigour with which our Medallist attacked an important problem. Notwithstanding its admitted preliminary character, this determination of the Sun's way by Campbell is of great interest; and we must all hope that as soon as suitable data have accumulated the work may again be taken in hand by our Medallist. It may be mentioned, by the way, that only last month Mr. H. D. Curtis left Mount Hamilton with his family, to carry on another five years' work in Chile.

The investigation of the solar motion to which I have just referred brought out some interesting facts which I may mention here. One of these was that the average velocity of the stars dealt with was 26·78 kilometres per second in a plane at right angles to the line of sight, while *in space* the average velocity was 34·10 kilometres per second. The deduced velocity for the Sun—namely, 19·9 kilometres per second—was therefore very much smaller than that of the average star of the system.

Another interesting deduction, drawn by our Medallist, concerned the relation between velocity in space and the visual brightness of the stars used in this investigation. Dividing these stars into three groups, of which the first consisted of stars of the third magnitude or brighter, the second of the stars between 3·1 and 4·0 magnitude, and the third of stars fainter than magnitude 4·0, Campbell obtained for the average velocities of the stars in these groups the figures 26·1, 32·3, and 38·88 kilometres per second respectively. This result, which Campbell considers to be in no way due to probable errors of observation, is a very important one, affecting as it does our ideas as to the relation between the proper motion and distance of stars, and it well deserves further examination.

I have devoted considerable time to remarks on the observation of spectroscopic binaries, and the determination of stellar velocities in the line of sight, because these are branches of work with the development of which Campbell has been so prominently and so honourably associated; but our Medallist has many other strong claims for recognition at our hands, and to some of these I must proceed to direct attention.

During the latter part of 1893 and the first half of 1894 Campbell devoted much time to a thorough examination of such

stars of the Wolf-Rayet type as were observable at Mount Hamilton. The immediate object of the work was to determine whether there was any analogy between these stars and the new star in *Auriga*, and it resulted in the discovery of many points of interest. It would be impossible in this Address to deal with these matters in any detail, but a few features may be mentioned. One point—at that time novel, but since well established —which came out strongly was the great variety of form and intensity assumed in these spectra by lines belonging to the same element. This was particularly the case with the hydrogen lines, which were found some dark and some bright, in different parts of the same spectrum : the dark hydrogen lines in some cases having bright borders, as if doubly reversed, while the bright lines varied from monochromatic lines to broad bands, being in some instances clearly single, and in others apparently multiple. Campbell's observations of spectra, including both dark and bright hydrogen lines, led him to the conclusion that in stars giving such spectra the bright lines are, as a rule, those of greater wave length, and the dark lines those of shorter wave length. Schuster has recently given theoretical grounds for accepting this as possible. Another conclusion is, that the intensities of the bright lines decrease, and those of the dark lines increase, towards the violet end of the spectrum.

Another interesting result was the discovery of a star surrounded by an envelope of hydrogen. This star—which was discovered at Harvard in the course of the Draper Memorial Surveys—is D.M. 30°, 3639, and is of below the 10th magnitude. It nevertheless yields a spectrum which is easily observable on account of the sharpness of its lines, of which 30 were measured by our Medallist in 1893, some of them appearing to be individual to this particular star. The great feature of interest was the behaviour of the $H\beta$ line. To quote Campbell's own words: "When the spectroscope was adjusted for the various parts of the spectrum the line at λ 5694 appeared essentially as a stellar point; the band at λ 4652 was broad but short, and lay wholly upon the continuous spectrum; but the line $H\beta$ was narrow and long, extending a very appreciable distance on each side of the continuous spectrum. When the slit was opened wide the $H\beta$ line became a circular disc, while the line λ 5694 and the band λ 4652 remained unchanged." The diameter of this disc was subsequently measured by the micrometer, and found to be about 5″. Campbell's observations of this star were confirmed by Runge in 1897, and by Keeler in 1898. Other stars of similar type have been examined for discs, but, so far as I am aware, this star remains up to the present a unique example of its class.

In connection with the variable behaviour of hydrogen lines, reference may be made here to the interesting observations of *Mira*, carried out by Campbell during the very favourable maximum of 1898. This star, as is well known, has a dark line

spectrum of Secchi's third type with bright hydrogen lines $H\gamma$, $H\delta$, $H\zeta$, $H\eta$, &c., and it was first examined with the Mills Spectrograph solely for the purpose of determining its velocity in the line of sight. Observations were made in 1897 and 1898, and measures of the dark line spectrum gave a fairly constant velocity of recession of 62·5 kilometres per second. But a comparison of the dark line with the bright line spectrum showed unmistakably that the latter is displaced towards the violet with reference to the former. Owing to the great brilliancy of the $H\gamma$ band, it was over-exposed on a number of the plates taken; but on 1898 August 29 a short exposure was made which enabled the structure of the band to be analysed. It was then found to be triple, being composed of three lines of which the central one was by far the strongest, that on the violet side having an intensity of about one-half, and that on the red side of about one-fourth, the intensity of the central line. The mean wave lengths determined for the three components were 4340·24, 4340·60, and 4340·91 respectively. Shortly afterwards Mr. Wright obtained photographs of the $H\delta$ band, and this proved to be also triple, the central line being much the strongest, and the other two about equal to each other in intensity. This band was also displaced towards the violet as compared with the dark line spectrum, and in the case of the component next the red the amount of the displacement agreed closely with that of the corresponding component of the $H\gamma$ line; but in the case of the two other components the displacement was considerably greater. About two months later further photographs were obtained of the $H\gamma$ and the $H\delta$ bands, when it was found that their character had changed, they being then apparently single lines; moreover the former had materially shifted its position, its wave length being determined as 4340·37; while on the other hand the single $H\delta$ line retained a position practically identical with that of the central component of the triple group observed at the earlier date. So far as the evidence at present available enables us to judge, this tripling of the bright hydrogen lines appears to only take place in the spectrum of *Mira* on the occasion of an exceptionally bright maximum, but it is to be hoped that further evidence on the point may be obtained. As to the cause of the change no explanation is as yet forthcoming, but Campbell is careful to point out that the shifting of the bright lines relatively to the dark line spectrum is not necessarily to be attributed to high velocities of incandescent hydrogen in the line of sight, but that it may be due to change of pressure or other physical causes. In any case the observations are of high interest. I may add that a visual examination of the spectrum of *Mira* by Professor Keeler, Professor Campbell, and Mr. Wright failed to show either $H\alpha$ or $H\beta$ as bright lines. Professor Campbell noted, however, that as the continuous spectrum became fainter other bright lines appeared, and two of these were apparently iron lines, and showed a displacement

towards the violet agreeing with that of the single $H\gamma$ and $H\delta$ lines.

I have, so far, dwelt almost entirely on our Medallist's work in connection with the spectroscopic examination of stellar objects; but, even at the risk of unduly extending this Address, it is desirable that I should also say at least a few words regarding his valuable contributions to other branches of spectroscopic research. On the occasion of the solar eclipse observed in India, in 1898 January, Campbell included in his programme an attempt to determine the law of rotation of the corona, by measurements of its velocity in the line of sight on opposite sides of the Sun's disc. On account of the high dispersion which it was necessary to employ, our Medallist concluded that it would be hopeless to attempt to deal with any other than the bright line portion of the coronal spectrum, and he determined, therefore, to base his observations on the green line, and not to reject the evidence afforded by even the lowest part of the corona. He further decided, after making some experiments, to employ a prism train in preference to a grating. The prism train used consisted of four compound and two single prisms, giving a combined deviation of $265° 41'$.

By a highly ingenious series of shutters he was enabled to get a photographic record of the bright green line in the corona spectrum side by side with portions of the solar spectrum on the same photographic plate, and measurements showed a relative velocity in the line of sight for the east and west sides of the corona of 6·2 kilometres per second, corresponding to a rotational velocity of 3·1 kilometres per second. Campbell, however, regarded this result as subject to a possible error of ± 2 kilometres per second, partly owing to errors of observation, but chiefly owing to the character of the bright line itself, the inner ends being over-exposed and the outer ends under-exposed. Thus, while the results of the attempts to determine spectroscopically, during the eclipse of 1898, the rotational speed of the corona were not so definite as could be wished, they were eminently suggestive, and will, it may be hoped, form the foundation for further work in this direction hereafter.

Our Medallist was among those who were successful in adopting the method of employing a moving photographic plate to record the succession of phenomena during a solar eclipse; and for use during the Indian eclipse of 1898 he devised an instrument which enabled him to take successively on the same plate photographs of the spectrum of the disappearing crescent, of the corona and of the reappearing crescent. This instrument had a Rowland grating placed about 5 inches in front of a camera objective of $2\frac{5}{32}$ inches aperture and $20\frac{3}{4}$ inches focal length; and the whole of the arrangements for controlling the exposures were characterised by great ingenuity and completeness.

The first and third exposures thus made yielded results of

high interest. The transition from dark to bright lines was indicated by the first exposure very definitely, and it was shown that before the continuous spectrum ceased recording some of the dark lines apparently disappeared. In other cases the dark lines and their corresponding bright lines coexisted until the continuous spectrum ceased to form a sufficiently bright background for the dark lines. Marked anomalies were also shown in the relative intensities of different portions of the dark and bright line spectra, but on these and many other points it is impossible for me to speak on the present occasion, and I will only refer to one other feature of the first exposure which appears to be especially worthy of note. Our Medallist found that in many—but not in all—cases, where dark and bright lines coexisted, the dark lines were displaced towards the violet by as much as four- or five-tenths of a tenth-metre: this effect, however, being almost wholly confined to the first exposure, and at the time of second contact. Campbell has shown strong reasons for believing that this result is not due to any instrumental defect; while, moreover, another negative (somewhat under-exposed, unfortunately) obtained on a moving plate with another instrument—a collimating spectrograph with a radial slit—showed the same effect for $H\gamma$ and $H\delta$ lines at both second and third contacts. Concerning the meaning of this effect Campbell says: "Assuming the reality of the displacement, we naturally consider its significance from the point of view of wave length. If this is a pressure effect, we conclude that the predominating absorption stratum for these lines is above the predominating radiation stratum. Whether this effect is general over the Sun's surface, or is purely local and confined to certain lines, is immaterial so far as the interpretation of these particular observations is concerned, provided that the pressure in the solar atmosphere increases towards the Sun's centre."

I have referred especially to Professor Campbell's work in connection with the Indian eclipse of 1898, but it must be remembered that the Indian expedition of that year is only one of many such expeditions which have had the benefit of his experience and enthusiasm. It is, in fact, impossible to overrate the importance of the influence which our Medallist has exercised on the eclipse expeditions which have during recent years been sent out from the Lick Observatory; and probably only those who have taken part in such expeditions can fully appreciate his powers of organisation, and his skill and resourcefulness in devising special lines of research and instrumental means for rendering such researches practicable.

Although I have touched upon so many instances of important work carried out by our Medallist it would be easy, did time permit, to treat of numerous other claims which he has created to recognition at our hands. Amongst these, for instance, are his researches on the spectra of nebulæ, including the comparison of the visual hydrogen spectra of the *Orion* nebula and of a

Geissler tube; his determinations—as a check on his stellar measurements—of the radial velocities of the Moon and of planets; his important work on the orbit and parallax of *Sirius*; his observations on the spectra of comets; and lastly, but by no means least, his most valuable investigations of the spectroscopic characteristics of temporary stars. Speaking of these latter researches, the Commissioners of the Académie des Sciences, MM. Lœwy, Callandreau, Wolf, Radau, Janssen and Deslandres, who in 1903 awarded to Professor Campbell the Lalande prize, said: "To him we owe the most thorough study of the numerous remarkable temporary stars of recent years; he has been able to follow to the last stages of their decline the most difficult of observation, and to recognise their more or less complete transformation into nebulæ." These observations would in themselves afford ample scope for lengthy comment, but I am compelled to pass them by with this mere mention. And now, in bringing this Address to a close, I can only express the hope that, incomplete as my record of our Medallist's work has been, it may yet suffice to indicate how greatly our science is indebted to him for important advances secured by researches most excellently planned, and carried out with a skill, persistence, and energy which command our highest admiration. That our Medallist may long be spared to continue the work he has so keenly at heart is our most earnest wish.

It is a matter of regret to us all that it has not been possible for Professor Campbell to be with us this afternoon to receive in person the medal which has been awarded to him. But in view of the fact that it is only a few months since he visited Europe, and of the important work which he has in hand at Mount Hamilton, Professor Campbell's absence, although, as I have said, a matter for regret, is not one for surprise. Moreover, we are not without a compensation. It has on many occasions been our pleasure to heartily welcome in this room Mr. Choate, for so many years the American Ambassador in this country; and now Professor Campbell's absence has afforded us the opportunity of extending an equally cordial welcome to Mr. Whitelaw Reid, who has succeeded Mr. Choate in his most important office, and who will, I am sure, also succeed him in the esteem and regard of the British nation.

There is a special fitness in Mr. Reid's presence here to-day, as I have learned that—by a peculiarly happy coincidence—he is the son-in-law of Mr. D. O. Mills, through whose munificence it was rendered possible not only to construct the Mills Spectrograph but also to organise and carry out those observing expeditions to Chile which have proved such an extremely valuable aid to Professor Campbell's scheme of research.

Mr. Reid, in handing you this medal which you have kindly undertaken to transmit to Professor Campbell I will ask you to

assure him of the very deep interest which we in England take in the important work which he is so successfully prosecuting, and to express to him our high appreciation of the influence which his researches have exerted—and still are exerting—on the development of astronomical knowledge.

The Meeting then proceeded to the election of Officers and Council for the ensuing year, when the following Fellows were elected :—

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